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ABSTRACT

This report contains a variety of material. There is first a brief summary of work done under the contract. This is followed by a detailed outline of a graduate seminar entitled "Modern Topics in Measurement and Scaling III." The six major divisions are: (1) introduction and philosophy of measurement; (2) mathematical and axiomatic foundations of measurement; (3) practical and theoretical issues of measurement in the social sciences; (4) language and measurement based on linguistic theory; (5) cognitive development and measurement; and (6) instructional theory and the teaching of measurement. Following this is a description of an experiment on the cognitive structure concerned with the names of the months of the year and their order. Appendix A is a published report which has been deleted from this document. Appendix B describes an experiment concerning a Broadbent "divided-attention" paradigm. Subjects were exposed to 20 lists of 4 simultaneous pairs of nouns; one word of each pair was presented auditorially and one visually. Subjects engaged in instructed, written-recall and following all lists, they received an unexpected modality recognition test. Over 30% of the items were detected during modality recognition. (Author/CTM)

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Final Report

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Project No. 1-0514
Grant No. OEC-9-71-0034 (508)

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MEASUREMENT SYSTEMS VIEWED AS COGNITIVE STRUCTURES

March 2, 1974

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The research reported herein was performed pursuant to a grant with the National Institute of Education, U.S. Department of Health, Education, and Welfare. Contractors undertaking such projects under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official National Institute of Education position or policy.

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National Institute of Education

INTRODUCTION

This final grant report discusses research done under the aforementioned National Institute of Education grant for the period of May 1971 through April 1973. The report is divided into three sections numbered I, II, and III. Section I concerns efforts on the part of the Principal Investigator to bring several separate lines of measurement-related work together. Section II concerns an exploratory study designed to assess the feasibility of deducing a cognitive structure from a pattern of reaction times to questions related to that structure. Section III concerns a continuing line of research on the question of to what extent measurable sensory attributes of an input stimulus are retained in memory. Appendix A is a paper published in the Journal of Verbal Learning and Verbal Behavior based on data collected prior to the grant but written during the grant period. Appendix B is a paper submitted for publication which is based on research conducted with the support of the grant.

During the period of the grant the Principal Investigator was assisted in his researches by Leonard Fisk and Satanand Sharma, both advanced graduate students in the School of Social Sciences at Irvine. Leonard Fisk was paid by funds from the research grant and Stan Sharma participated voluntarily in the project. Both completed their Ph.D. degrees under the Principal Investigator in the summer of 1973 and are now, respectively, a visiting lecturer in the Department of Psychology, California State University at San Francisco and a research associate, Computer Science Department, U.C.L.A. Fisk's thesis was somewhat related to component III of this final report, whereas, Sharma's thesis was concerned with another project.

The Principal Investigator, in addition to the Research Assistant, had funds for half-time work on the grant during the summers of 1971 and 1972 as well as travel to a professional meeting. The summer research was conducted half in the University of California, Irvine, and half at the University of Illinois for the summer of 1971 and all at Irvine for the summer of 1972. The travel to the professional meeting was used to read a paper to the Mathematical Psychology Meetings during the summer of 1971 entitled:

Batchelder, W.H. and Johnson, R.A.

Form similarity in recognition memory.

Paper read at Annual Mathematical

Psychology Meetings, Princeton, N.J.,

August 1971.

In addition to this paper a second paper related to component III of the final report was read by the project Research Assistant entitled:

Batchelder, W.H. and Fisk, L.

Modality shift and proactive interference

in short term memory. Paper read at

Western Psychological Association Meeting,

Portland, Oregon, 1972.

I. LITERATURE SYNTHESIS

During the first year of the grant (and especially the summer of 1971) the Principal Investigator attempted to bring together a number of lines of measurement-related research. During this period hundreds of articles and books were assembled and studied with the assistance of Leonard Fisk, the project Research Assistant. The winter quarter of the 1972-73 school year provided an opportunity to bring some of these notions together in a graduate seminar taught at Irvine entitled "Modern Topics in Measurement and Scaling III."

The students seemed to develop well in the three-quarter seminar and produced such term papers as: "Measurement in the Carolina Islands," "Measurement in Music," "Measurement of Opinion," "Educational Practices in Measurement," etc. Since much of the work under the grant was devoted to bringing together several lines of measurement-related literature and this work went, in part, toward designing and teaching this course, this section will consist of a possible course outline for a three-quarter measurement course based, in part, on revisions suggested by the Principal Investigator's teaching experience. The selected format of a course outline with suggested texts and articles could be viewed as a convenient format for indicating the nature of the literature synthesis funded by the grant.

The course envisioned in the outline might best be viewed as an ideal rather than a practical course. It would take at least three quarters to begin to cover all the material captured within its organization, and the

students would have to be very bright and broadly educated. Nevertheless the course outline and appended readings convey the results of the synthesis of measurement-related research.

The course outline breaks into six sections denoted by capital section headings. The first heading is "introduction" and this section of the course is designed to familiarize students with some of the more elementary philosophy of measurement, as well as, to increase general awareness of the importance of measurement. The second section is entitled, "foundations of measurement," and after appropriate mathematical pre-requisites are dealt with, the student is exposed to the very difficult axiomatic foundation of measurement. The third section deals with practical and theoretical issues in the area of "measurement in social science." Here the student will survey extant and previously studied quantitative techniques in social science with a clear head about their measurement-theoretic content.

Section 4 is entitled "language and measurement," and it represents the first point at which the course departs from well-trodden channels. Basically this section presupposes a bit of linguistic theory on the part of the student, and it discusses different issues concerning how measurement notions are expressed from a linguistic standpoint.

Section 5 is called "cognitive development and measurement" and it is concerned with the question of what a child acquires in the way of measurement notions as well as how he acquires these notions. Piaget's stage-developmental theory is the main theory taken up in this section and a lot of relevant empirical work is integrated by Piaget's notions.

Finally section 6, entitled "measurement education," shifts the focus of the course to current educational practices in the measurement area.

There the student will clearly see how measurement is oddly divided between pure mathematics and science. Also the relationship between the suggested stages of measurement education will have an interesting relationship with the stages of section 5 and the axioms of section 2. What follows is the outline for the course.

1. INTRODUCTION TO MEASUREMENT

A. Nature of measurement

1. What constitutes measurement
2. What is a measurement device
3. Prepare exhaustive list of measurement devices
4. Importance of measurement in everyday world

B. History

1. History of measurement of weight, length, and temperature
2. History of different units
3. Other measurement in the physical sciences
4. Early history of measurement in the social sciences
 - a. Economics
 - b. Psychophysics
 - c. Intelligence

C. Philosophy of science

1. Standard theoretical notions about measurement
2. Measurement and theory construction
3. Brief overview of foundations (II)

D. Selected references for reading reserve

1. Campbell, N.R. Physics: the Elements, Dover, 1957.
2. Churchman, C.W. and Ratoosh, P. (Eds.) Measurement: Definitions and Theories. New York: Wiley, 1959.
3. Dantzig, T. Number: the Language of Science. New York: MacMillan, 1949.

4. Kayan, C.F. (Ed.) Systems of units: national and international aspects. Washington: American Association for the Advancement of Science, 1959.
5. Kisch, B. Scales and Weights. New Haven: Yale University Press, 1965.
6. Lerner, D. (Ed.) Quantity and Quality. New York: Free Press of Glencoe, 1961.
7. Selected philosophy of science texts by such writers as Hemple, Hanson, Quine, and Cohen and Nagel.
8. Stevens, S.S. Measurement and man. Science, 1958, 127, 383-389.

2. FOUNDATIONS OF MEASUREMENT

- A. Mathematical background
 - 1. First and second order logic
 - 2. Set theory and relational structures
 - 3. Set-theoretic foundations of the axiomatic method
 - 4. Properties of the number system
- B. Formal notions of measurement
 - 1. Representation and uniqueness theorems
 - 2. Types of measurement (e.g. extensive, derived, etc.)
 - 3. Types of scales
- C. Examples of formal measurement systems
 - 1. Classificatory systems
 - 2. Semi-orders
 - 3. Extensive systems
 - 4. Equal-difference structures
 - 5. Conjoint measurement systems
 - 6. Paired-comparison systems
- D. Dimension analysis (Ch. 10)
- E. Comparison of different formalisms
 - 1. Scott, Suppes, Luce, Krantz, Tversky, et. al.
 - 2. Campbell
 - 3. Pfanzogl, J.
 - 4. Rozeboom
- F. Selected references for reading reserve

1. Krantz, D.H., Luce, R.D., Suppes, P., and Tversky, A.
Foundations of Measurement. New York: Academic Press, 1971,
Vol. 1 (a suitable text for this section of the course)
2. Krantz, D.H., and Tversky, A. Conjoint-measurement analysis of
composition rules in psychology. Psychological Review. 1971,
78, 151-169.
3. Luce, R.D. and Tukey, J.W. Simultaneous conjoint-measurement:
a new type of fundamental measurement. Journal of Mathematical
Psychology, 1964, 1, 1-27.
(also numerous related J.M.P. articles)
4. Pfanzagl, J. Theory of Measurement. New York: Wiley, 1968.
5. Suppes, P. Introduction to Logic. Princeton, New Jersey:
van Nostrand, 1957.
6. Selected texts on dimension analysis

3. MEASUREMENT IN SOCIAL SCIENCE

- A. Measurement and statistics
 - 1. Steven's scale controversy
 - 2. Non-parametric statistics
 - 3. Invariance under scale transformation
- B. Measurement with physical correspondence
 - 1. Psychophysical scaling
 - 2. Measurement of utility and subjective probability
- C. Measurement without a physical correspondence
 - 1. Factor analysis
 - 2. Scaling (especially multi-dimensional)
- 3. Measurement of attitudes
 - 4. Measurement of intelligence
- D. Selected references for reading reserve
 - 1. Anderson, N.H. Functional measurement and psychophysical judgment. Psychological Review. 1970, 77, 153-170.
 - 2. Coombs, C.H. A Theory of Data. New York: Wiley, 1964.
 - 3. Eckart, C. and Young, G. The approximation of one matrix by another of lower rank. Psychometrika. 1936, 1, 211-218.
(other selected articles from the same journal)
 - 4. Harman, H.H. Modern Factor Analysis. Chicago: University of Chicago Press, 1960, 1967.
 - 5. Selected statistics texts such as Hays and Seigle's non-parametric statistics book.
 - 6. Shepard, R.N. Metric structures in ordinal data. Journal of Mathematical Psychology. 1966, 3, 287-315.

7. Stevens, S.S. Measurement, statistics, and the schemapiric view. Science. 1968, 161, 849-856.
8. Thurstone, L.L. The Measurement of Values. Chicago: University of Chicago Press, 1959.
9. Torgerson, W.S. Theory and Methods of Scaling. New York: Wiley, 1958.

4. LANGUAGE AND MEASUREMENT

- A. Introduction to linguistics (supposes some prior work)
 - 1. Syntax and transformation grammar
 - 2. Semantics and transformational semantics
 - 3. Psycholinguistics
- B. Comparative adjectives
 - 1. Spatial theories (e.g., DeSoto and Huttenlocher)
 - 2. Linguistic theories (e.g., Clark)
 - 3. Logic-linguistic theories (e.g., Narens)
- C. Adverbs
 - 1. Verb pacing (e.g., Cliff)
 - 2. Time adverbs
- D. Reference systems and nouns
 - 1. Time tenses and the semantics of time
 - 2. Spatial location
 - 3. Count vs. mass nouns and pluralization
- E. Meaningfulness, logic, and transformation of scales
- F. Selected references for reading reserve
 - 1. Chase, W.G. and Clark, H.H. Mental operations in the comparison of sentences and pictures. Cognition in Learning and Memory. L. Gregg (Ed.) New York: Wiley, 1973.
 - 2. Chomsky, N. Aspects of the Theory of Syntax. Cambridge: MIT Press, 1965.
 - 3. Cliff, N. Adverbs as multipliers. Psychological Review, 1959, 66, 27-44.

4. Clark, H.H. Semantics and comprehension. In Sebeok, T.A. (Ed.) Current Trends in Linguistics, Vol. 12: Linguistics and Adjacent Arts and Sciences. The Hague: Mouton, 1974.
5. De Soto, C.B., London, M., and Handel, S. Social reasoning and spatial paralogic. Journal of personality and social psychology. 1965, 2, 513-521.
6. Huttenlocher, J. and Strauss, S. Comprehension and a statement's relation to the situation it describes. Journal of Verbal Learning and Verbal Behavior. 1968, 7, 527-530.
7. McKay, J.C. Some generative rules for German time adverbials. Language. 1968, 44, 25-50.
8. Narens, L. Why tall pygmies are short. Social Sciences Working Papers, No. 13. School of Social Sciences, University of California, Irvine, November 1972.
9. Rescher, N. Semantic foundations for the logic of preference. In N. Rescher (Ed.) The Logic of Decision and Action. Pittsburgh: University of Pittsburgh Press, 1967, 37-79.
10. Suppes, P. Measurements, empirical meaningfulness, and three value logic. In C.W. Churchman and P. Ratoosh (Eds.) Measurement: Definitions and Theories. New York: Wiley, 1959.

5. COGNITIVE DEVELOPMENT AND MEASUREMENT

A. Nature of developmental psychology

1. Methodology
2. Theory construction
3. Major theories

B. Piaget's developmental stage theory

1. Identifying an attribute
2. Conservation
3. Comparing
4. Seriation
5. Subdividing
6. Counting
7. Comparison of stages to axioms in foundations work (II)

C. Experimental work

1. Work on Piaget's stages
2. Work on space reference
3. Work on area and length
4. Work on other attributes

D. Selected references for reading reserve

1. Berlin, H. and Franklin, I.C. Logical operations in area and length measurement: age and training effects. Child Development, 1962, 33, 607-618.

(other selected articles from that journal).
2. Bunt, L.N.H. The Development of Ideas of Number and Quantity According to Piaget. Croningen: Walter, 1951.

3. Elkind, D. and Flavell, J.H. (Eds.) Studies in Cognitive Development: Essays in Honor of Jean Piaget. New York: Oxford University Press, 1974.
4. Flavell, J.H. Stage-related properties of cognitive development. Cognitive Psychology, 1971, 421-453.
5. Gelman, R. Logical capacity of very young children: number invariance rules. Child Development, 1972, 43, 75-90.
6. Gelman, R. The nature and development of early number concepts. In H. Reese (Ed.), Advances in Child Development and Behavior. New York: Academic Press, 1972, Vol. 7, 115-167.
7. Inhelder, B. and Piaget, J. The Growth of Logical Thinking. Basic Books, 1958.
8. Klahr, D. and Wallace, J.G. The role of quantification operators in the development of conservation of quantity. Cognitive Psychology, 4, 1973, 301-327.
9. Piaget, J. The Child's Conception of the World. Paterson, N.J.: Littlefield, Adams, 1960.
10. Pufall, P.B. and Shaw, R.E. Analysis of the development of childrens' spatial reference systems. Cognitive Psychology, 1973, 5, 151-175.
11. Witz, K. Recent technical reports on his project to mathematize Piaget's theory.

6. MEASUREMENT EDUCATION

A. Instructional theory

1. Theories of learning
2. Cognitive instructional theories (e.g., Bruner) vs. operant instructional theories (e.g. behavior modification).
3. Programmed instruction in mathematics and science.

B. Teaching of measurement

1. Relationship to mathematics teaching
 - a. Examine textbooks on reserve
 - b. Study the Strands report
 - c. New math
2. Relationship to science teaching
 - a. Units and scales
 - b. Metrization
 - c. Learning to measure such things as money, time, dates, length, etc.
 - d. Examine elementary and secondary science textbooks on reserve

C. Evaluation of measurement teaching

1. Relationship of Strand stages to axioms for a measurement system
2. Relationship of teaching to developmental work

D. Selected references for reading reserve

1. Craig, G.S., et. al. Science Today and Tomorrow series. Ginn, 1956.
2. Goldberg, A. A generalized instructional system for mathematical logic. Technical Report 179. Institute for Mathematical Studies in the Social Sciences, Stanford University, 1973.

3. Hone, E.B., Joseph, A., Victor, E., and Brandwein, P.F. A sourcebook for Elementary Science. New York: Harcourt, Brace and World, 1962.
4. Meister, M., et. al. Wonderworld of Science Series, Scribner's, 1955.
5. Metrization of America. U.S. Government pamphlet.
6. Selected elementary and secondary science and mathematics texts.
7. Snelbecker, G.E. Learning Theory, Instructional Theory, and Psychoeducational Design. New York: McGraw Hill, 1974.
8. Strands reports. Strands scope and sequence charts. The 8 volume modern school mathematics series by Houghton Mifflin.
9. Suppes, P. Toward a behavioral psychology of mathematical thinking and the psychology of arithmetic. Both in Learning about learning. J. Bruner (Ed.) OE-12019 Cooperative Research Monograph No. 15 U.S. Dept. of Health, Education, and Welfare, 1963.
10. Suppes, P., Jerman, M., and Brian, D. Computer-Assisted Instruction: Stanford's 1965-66 Arithmetic Program, New York: Academic Press, 1968.

II COGNITIVE STRUCTURE OF MONTHS SYSTEM

The purpose of this experiment was to assess the feasibility of deducing the cognitive structure of a measurement system by analyzing the pattern of reaction times given by a subject to a set of questions about the cognitive domain. The system of 12 months provides us with an interesting non-trivial measurement system. First, all college sophomores can be expected to know this system quite well. Second, there are several reasonable alternatives for how the system might best be represented detailed in the next paragraph.

If subjects are asked to state the months, most report them in order starting with January and proceeding through December. There are, however, several ways of representing the months that would predict such a response. First, suppose the months are stored as an ordered list with January as the first month. Such representation is depicted in Fig. 1a. The question causes the subject to access the word month and recite the list in the usual order. The stimulus for the next month is always the preceding month; and the overall plan for answering the question, which is presumably set into motion by the question, would be to proceed through the list called months and vocalize each item.

An objection to the preceding structure would be that subjects are perfectly able to recite the months starting with any particular one. It would appear that silent progress through the list starting with January and proceeding to the requisite starting month is not required. Further, there are not noticeable gaps in the smoothness of the response output

when the subject goes from December to January. A second structure for representing the months is depicted in Fig. 1b. Here they are represented as an ordered list with no particular starting month. Such a representation would seem to be consistent with all the facts that we have mentioned so far.

An alternative structure equally consistent with the preceding remarks is depicted in Fig. 1c. Basically this structure could be thought of as a repetitive calendar or perhaps stacking multiple linear representations together. There are other possible structures for representing the months; however, the three possibilities in Fig. 1 reflect the main possibilities suggested by subjects.

 INSERT FIG. 1 ABOUT HERE

In addition to the questions about the months discussed so far, subjects are able to answer such questions as: 1. "Which months are in the summer?" 2. "How many months have more than 5 letters in them?" 3. "How many months start with the letter M?" These facts suggest that in addition to the interconnection structure represented by the arrows in Fig. 1, the subject may store certain facts or attributes with each month including its season, major holidays, number of days, etc.

Finally, subjects are able to become quite facile at naming the months in a reverse order starting with any particular one; consequently, the structures in Fig. 1 may or may not be best depicted as having reverse arrows connecting each month with its predecessor. However, since subjects are somewhat awkward at first, in the reverse naming task, there is the

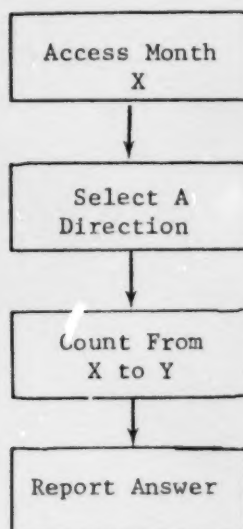
possibility that subjects develop some sort of algorithm for the reverse order based on their unidirectional structure.

The purpose of the following experiment was to see if any evidence could be gained about the cognitive structure of months in a setting where subjects are required to state a number as an answer to the following sort of question: "How many months are there from October to March?" (Correct answer is 5, i.e., the first month is to be included.) There are, of course, $12^2 = 144$ such questions, where it is understood that questions like "How many months from March to March?" are correctly answered by 0 or 12.

Informally, our theoretical assumptions will be as follows:

- A₁. There is some cognitive structure, S , that represents the structural way in which the month system is organized.
- A₂. Subjects comply with the task of stating answers to such questions as "How many months from X to Y ?" by applying an algorithm, A , to S yielding the answer.
- A₃. Instructions that emphasize speed rather than accuracy in the answer will result in occasional errors in exercising the algorithm. However, these errors will result in answers that are "close to" to correct answer.

- A₄. The algorithm for our set of questions can be thought of as a serial counting process with the following structure:



- A₅. The month X access reaction time is a random variable, X_1 , where the i refers to the month number starting with January as one. The incrementing reaction time for going from month j to $j+1$ in the forward direction is a random variable, Y_f , independent of j and the number $|i-j|$. Similarly the backward incrementing time from month j to $j-1$ is given by the random variable, Y_b , independent of j and the number $|i-j|$.
- A₆. That total reaction time to answer the question "How many months from month i to month j " is given by the random variable

$$T_{ij} = \begin{cases} x_i + \sum_{k=1}^{f(i,j)} Y_f + \epsilon & \text{if forward direction} \\ & \text{selected} \\ x_i + \sum_{k=1}^{12-f(i,j)} Y_b + \epsilon & \text{if backward direc-} \\ & \text{tion selected,} \end{cases}$$

where ϵ is a "garbage" random variable; x_i , all Y_f s and Y_b s, and ϵ are independent; and $f(i,j)$ is the correct number of months for the question.

After some informal data gathering on friends, a pilot study of four subjects was conducted by Leonard Fisk, the Research Assistant on the grant. While the results were somewhat promising it was decided not to conduct a more extensive experiment at that time. What follows is the method, results, and discussion of that pilot experiment.

METHOD

Subjects. The subjects were four University of California, Irvine undergraduate students. They received course credit for "Introductory Psychology" by participating in the experiment.

Method. The subjects were run one at a time. Each subject was seated in a small room with the experimenter. A black shield separated the experimenter from the subject. After some short, simple instructions were read and a few examples run, the subjects were given all 144 questions of the form "How many months from month i to month j ?" where i and j were pronounced aloud by the experimenter. Immediately after pronouncing month j , the experimenter started a stop watch, and as soon as the subject spoke

a number in answer, the watch was stopped. The response time and the answer were recorded by the experimenter in a 12×12 matrix and the next question was asked. The experimenter offered occasional short rests for the subject, and proceeded otherwise through the entire set of 144 questions in a randomly determined order. Two of the four subjects were encouraged to respond as rapidly as possible; whereas, the other two were told to emphasize accuracy.

RESULTS

Error Data. Subjects J.R. and B.H. were instructed to respond rapidly and made 21 and 43 errors, respectively. Subject L.F. and K.K. were instructed to be accurate and made 6 and 20 errors, respectively. Table 1 presents the distribution of errors for each subject over the difference between the response made and the correct answer.

 INSERT TABLE 1 ABOUT HERE

Table 1 shows that almost all of the errors that subjects made were within one unit of the correct response. All subjects show errors of -1 in more preponderance than errors of +1; however, substantial numbers of the +1 error type suggest that subjects overshoot the count quite often.

Inspection of the actual errors made is revealed in Table 2.

 INSERT TABLE 2 ABOUT HERE

Table 2 shows that most of the errors occurred for the intermediate

numbers of possible interviewing months. The upswing through 8 and 9 might represent chance; however, another possibility suggested by the analysis of the latency data is that it is in the region of 8 and 9 that the subject decides to count backward from X_j to X_i rather than forward from X_i to X_j . These cases then represent the most difficult applications of the backward count algorithm as well as the most difficult applications of the forward count algorithm.

Latency Data. Figure 2 presents to mean response times for each subject to the questions as a function of the correct number, $f(i,j)$. Each point on the graph is an average of 12 points less the error response time cases. All the four subjects show a linear-like increasing trend up to $f(i,j)$ s of 8 followed by a steeper linear-like drop from 9 to 12. These data are supportive of assumptions A_5 and A_6 that a basically counting algorithm is used to go either from i to j or backwards from j to i . The steeper slopes from $f(i,j) = 8$ to $f(i,j) = 12$ suggest that the counting operation takes longer from j backward to i . This is likely to be due to unfamiliarity with the task of reverse listing the months. More data and more statistically motivated analyses would be required to make a case for our class of models stronger.

 INSERT FIG. 2 ABOUT HERE

Any of the structures in Fig. 1 is consistent with the data pattern presented thus far. Fig. 3 presents the response time averaged over subjects as a function of the "from month" (i) and the "to month" j . Each point is based on 48 observations minus error observations. It seems

clear that there is not a big effect of start month and stop month on response times. This fact seems supportive of cognitive structures that do not have January as the lead term on an ordered list (see Fig. 1). Overall, January and also December seem somewhat lower than most months; however, this slight effect, if significant in a larger experiment, could be consistent with some bias on a structure like Fig. 1b.

 INSERT FIG. 3 ABOUT HERE

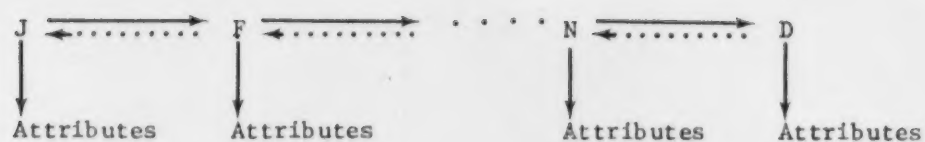
CONCLUSIONS

The main conclusion from this pilot experiment is that it is quite reasonable to test the adequacy of a cognitive structural model coupled with a algorithmic dynamical processing model in a task such as ours. The error pattern data of Tables 1 and 2 support the idea of an algorithmic count which is executed rapidly and not without error on a cognitive structure. The linear-like response times of Fig. 1 are additional strong support for such a model.

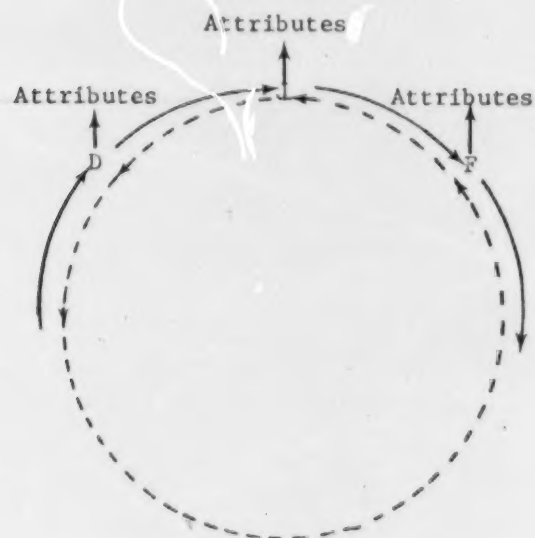
Therefore there is every reason to suspect that if a concerted experimental effort were made in such a study of ordered, classificatory measurement systems such as the months, the days, the seasons, etc., the results would strikingly support the sort of serial, algorithmic models found in other cognitive areas. Such a project was not undertaken during the period of the grant; however, if an interested student becomes available, such a study would make a good Ph.D. dissertation.

FIGURE CAPTIONS

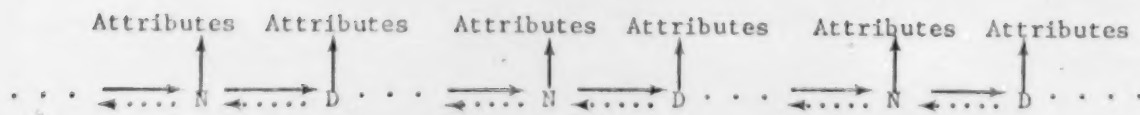
- Fig. 1 Possible cognitive representations for month system.
- Fig. 2 Individual subject latency curves as a function of the correct answer.
- Fig. 3 Average latency curves as a function of starting and stopping month.



1a. Ordered list with origin



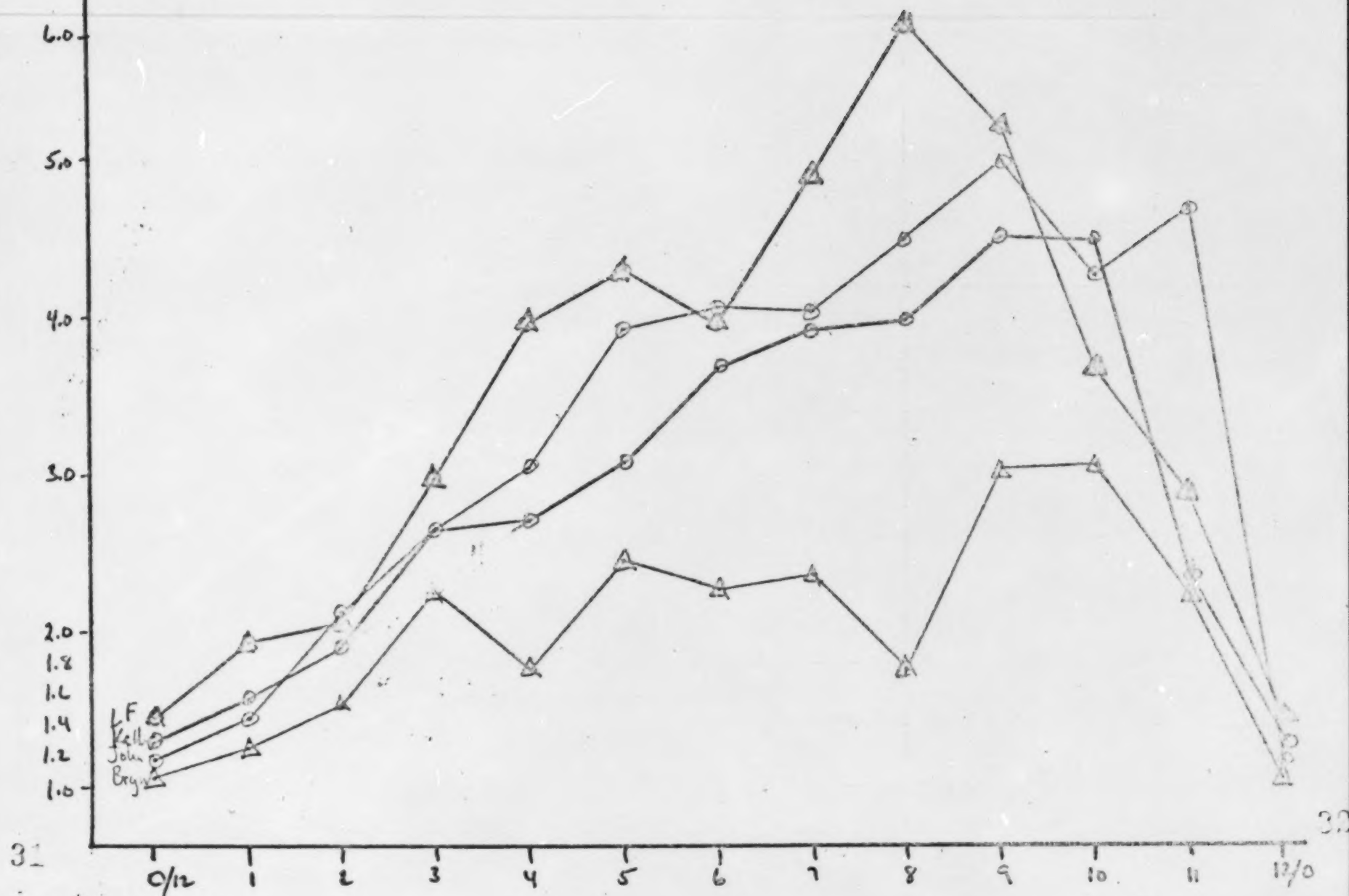
1b. Ordered list with no origin



1c. Multiple calendar stack

FIG. 1

Latencies for correct resp. organized
by distance betw. month pairs.



the "from" & "to" added together, i.e. Jan. contains latencies of all pairs having Jan mentioned, either 1st or 2nd

4.0

3.5

3.0

2.75

2.5

to
mean
from

Jan

Feb

Mar

Apr

May

Jun

Jul

Aug

Sept

Oct

Nov

Dec.

30

Fig 3

34

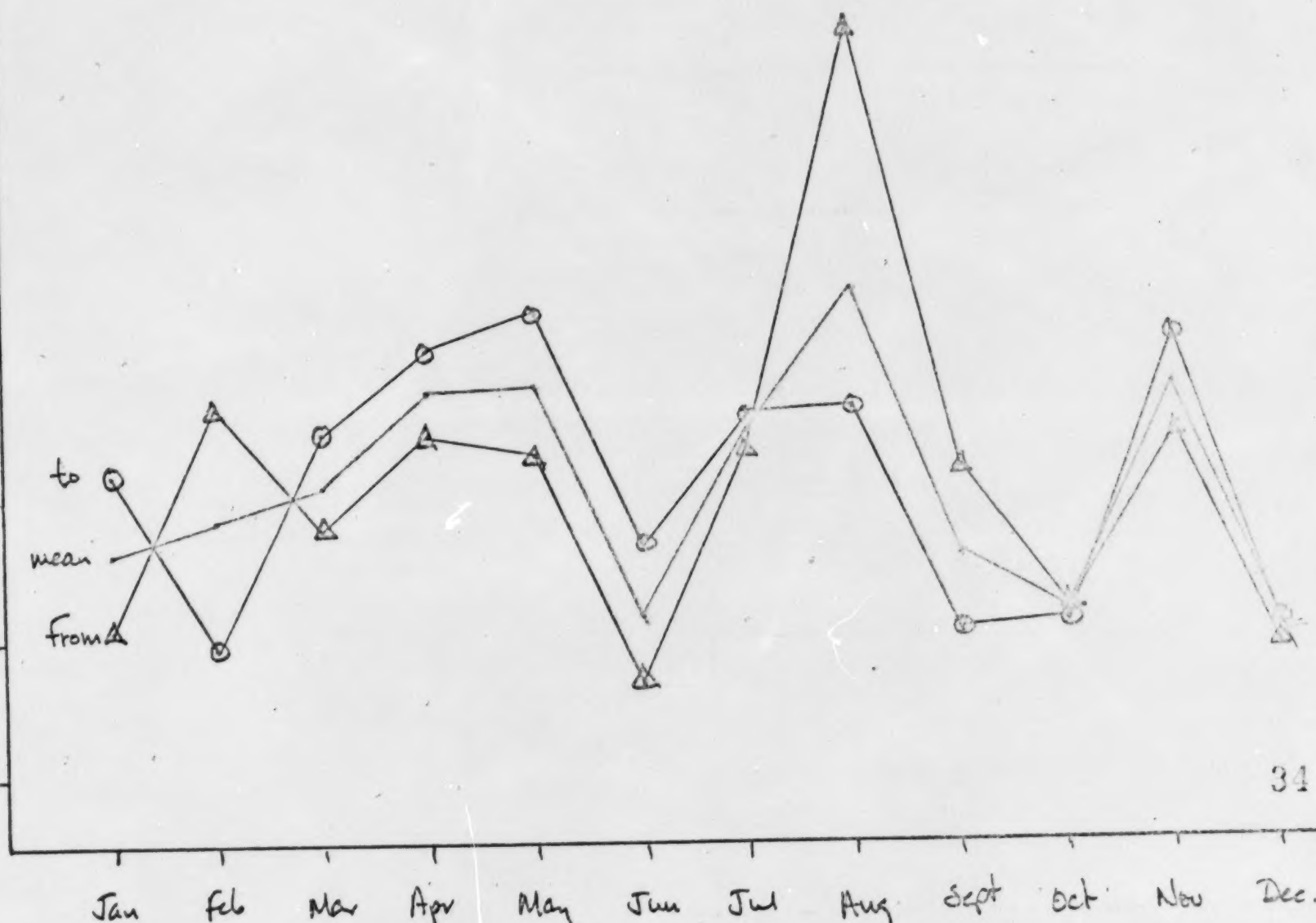


TABLE 1

Distribution of errors over subjects in months experiment.

		<u>Subject</u>			
Errors in terms of distance from correct response		J.R.	B.H.	L.F.	K.K.
	< -3	0	0	0	1
	-3	2	0	0	0
	-2	0	0	1	3
	-1	13	23	2	9
	0	--	--	-	-
	1	4	19	2	6
	2	1	0	1	0
	3	0	1	0	0
	> 3	1	0	0	1
		21	43	6	20

TABLE 2

Frequencies of errors as a function of correct answer combined over subjects.

<u>Correct Answer</u>	<u>Error Frequency</u>
0 (or 12)	1
1	1
2	3
3	10
4	8
5	8
6	8
7	9
8	14
9	17
10	9
11	2
	90

III MEMORY FOR MEASURABLE SENSORY ATTRIBUTES OF AN INPUT

One of the research projects conducted under the grant concerned the question of to what extent and for what time periods is measurable sensory information in an input stimulus held in memory. For example, any grammatical and meaningful handwritten message conveys to the reader some information of a linguistic form. In addition to and quite independent from this consideration, the input has certain measurable qualities such as color of ink, thickness of letters, spacing and density properties, etc.

Most memory theories (see the two papers: Bray and Batchelder (1972), and Batchelder and Sharma (1974), appendices A and B, respectively) follow the lead of the computer analogy (Arbib, 1972) and assume that the memory trace of an input is constantly transduced or transformed in order to remove irrelevant sensory attributes and in order to extract relevant semantic-like attributes. Such theories would seem to imply that the mind could measure the sensory-like attributes of an input accurately only immediately after the input occurs.

A less frequently espoused theory would hold that the memory for an input necessarily has a "sensory embodiment" (see Batchelder and Sharma, p. 11, Appendix B). Such a theory would hold that the mind uses measurable stimulus attributes as key to its memory cross-referencing system quite unlike a computer's address-accessible memory codes.

In the period prior to the grant, the Principal Investigator had begun experimental research on the memory for sensory attributes of a stimulus with one of his students, Norman Bray, at the University of Illinois. During the year involving the Principal Investigator's transfer to the University of California at Irvine, this completed research was shelved. However, during

the first summer of the grant period (summer of 1971) the Principal Investigator spent two weeks completing the data analysis and write up of the Bray and Batchelder paper (see Appendix A) and it was published in Journal of Verbal Learning and Verbal Behavior. During the late spring and early summer of the second year of the grant, the Principal Investigator designed and ran a second study related to this line of research with one of his graduate students (now Dr. Stan Sharma). This research is further described in Appendix B and the outcome strongly favors the position that the human memory does not eliminate semantically irrelevant sensory detail in its memory system. While a computer quickly forgets whether its information originally came from teletype, punch cards, paper tape, or disk; the human memory does not readily forget such detail.

Appendix A

Bray, Norman W.; Batchelder, William H. Effects of Instructions and Retention Interval on Memory of Presentation Mode. Journal of Verbal Learning and Verbal Behavior 11, 367-74 (1972)

Appendix A was removed from this document prior to its being submitted to the ERIC Document Reproduction Service.

Title: Memory for Presentation Mode in a Mixed Modality
Broadbent Paradigm¹

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Broadbent Paradigm¹

Authors: William H. Batchelder
Satanand Sharma²

Index: (1) Divided attention paradigm
instructed recall order

(2) Recognition
memory for input mode of words

MEMORY FOR PRESENTATION MODE IN
A MIXED MODALITY BROADBENT PARADIGM¹

William H. Batchelder and Satanand Sharma²

University of California, Irvine

Abstract

In a Broadbent "divided-attention" paradigm, subjects were exposed to 20 lists each consisting of 4 simultaneous pairs of nouns from two categories separated by one second each. One word of each pair was presented auditorially and one visually. After each list, subjects engaged in instructed, written-recall; and following all lists, they received an unexpected modality recognition test. Over 30% of the items were detected during modality recognition despite the paradigms heavy processing demands and immediate recall. The implications for memory theories of this experiment and several similar studies with a free recall paradigm were discussed.

MEMORY FOR PRESENTATION MODE IN
A MIXED MODALITY BROADBENT PARADIGM¹

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University of California, Irvine

Bray and Batchelder (1972) and Hintzman, Block, and Inskip (1972) have shown that in a standard free recall paradigm involving mixed auditory and visual presentations, subjects are able to perform well above chance on a post-task modality recognition test (MR). In both studies, MR rates³ were at or beyond the .75 level despite, in the Bray and Batchelder study, a 15 minute interpolated, unrelated task, and in the Hintzman, et al., study, an average of 3.5 interpolated 18 item, mixed modality lists. Both studies had conditions where the MR was given unexpectedly; and, taking both studies together, the MR rate did not increase with either pre-instructing subjects about the MR or with decreasing the time between original presentation and the MR. While previously not-recalled words had lower MR rates than recalled words in the Hintzman, et al., study (but not in Bray and Batchelder), MR rates on not recalled words were still quite high (.69 in Hintzman, et al.; .83 in Bray and Batchelder). A two-state correction-for-guessing model suggests that from 38% to 66% of the not-recalled items which were recognized had sufficient information in memory at the time of MR to support modality differentiation. This information was obviously not in short term memory as conventionally treated in the literature.

The finding that modality information endures as an attribute of memory might seem surprising since we do not seem to make use of modality in deriving the semantics of a word (c.f., Norman, 1968). Further, the modality recognition results seem to place considerable strain on memory systems such as Morton (1970) and Norman and Rumelhart (1970) which postulate that information about input attributes is eliminated by the memory system as an item is processed into its semantic attributes. Arbib (1972, p. 15) summarizes the position of these computer motivated, information transformation memory theories nicely by suggesting to the reader that he can demonstrate to himself how the human memory eliminates irrelevant information by seeing if a friend can perform above chance in a six-word, mixed-script-word and printed-word free recall task in a post-task printing-style recognition test. Arbib confidently asserts that "about 9 out of 10" human subjects can not perform above chance in such a task; yet, Hintzman, et al. (1972) in their Exp. II very strikingly disprove Arbib's claim with 144 words!

Under incidental MR instructions Bray and Batchelder (1972) found no evidence for clustering by modality in the recall data. Nevertheless, Murdock and Walker (1969), Hintzman, et al. (1972), and Nilsson (1973) have obtained some evidence for clustering by modality in such designs. One possibility consistent with this finding as well as the high MR rates would be that auditory and visual items are "tagged" separately in long term memory in such a way that retrieval strategies directly interact with the modality tag. It is difficult to see the adaptive role of placing such importance on modality; however, it is possible that the way in which we "call to mind" an experience is to imagine the experience in a sensory-like manner. In normal routine tasks, the sensory-like properties could be below awareness; however, in dreams, trances, hypnagogic states, etc. the

sensory character of a memory is more immediately available to awareness.

Even if the "sensory tag" is an important attribute in memory retrieval, it is surely not the only one. If this is so, then pre-instructing subjects about the MR should increase the importance of the sensory tag with a consequently greater indication of its utilization in retrieval than for the incidental MR condition. Nilsson (1973) did find considerably more modality clustering in his instructed condition; however, again, Bray and Batchelder (1972) found no such evidence. Overall, it appears that clustering by input modality is a possibility in free recall and that instructions to emphasize the modality factor will increase such clustering when it occurs.

The present study investigates the endurance of the modality attribute in a very demanding Broadbent divided-attention paradigm with simultaneous auditory and visual inputs. Subjects each encountered 20 short lists of 8 words each followed by immediate, order-instructed recall. Each list consisted of four words from each of two categories, and the presentation of a list was by 4 simultaneous pairs of words with one word presented auditorially and the other visually. Following the 20th list, there was an unexpected MR. Since the Broadbent paradigm involves fast rates of simultaneous presentations and immediate recall from a "short term" memory, it provides an interesting test of the possible long term retention of modality information. Further, by differentially instructing immediate recall to be by a modality order or a category order, it is possible to assess the extent to which the importance of the modality attribute can be manipulated.

Method

Design. Each subject received 20 lists of 8 nouns with each list composed of four instances from each of two categories. Each list comprised four pairs of items, and each pair was presented simultaneously, one word auditorially and the other visually, with slightly more than a second interval between pairs. The presentation schedule for all lists was as follows:

Auditory - $x_1 y_2 x_3 y_4$

Visual - $y_1 x_2 y_3 x_4$,

where x s denote one category and y s the other, e.g.,

Auditory - pool trumpet sailing violin

Visual - piano polo drum hunting.

Following each list, there was a brief 20 second written-recall period where subjects were differentially instructed as to their recall order and two seconds later the next list was presented. A blank slide triggered the start of recall and an auditory "beep" terminated recall and signalled that in two seconds the next list would appear. Following the 20th list, an unexpected modality recognition test (MR) was given to subject which consisted of all 160 words typed in a random order. The subject was instructed to check A or V for each word depending on whether the subject thought the word had been presented auditorially or visually.

There were five groups in the study which corresponded to the way the subject was instructed to order his recall after each list as follows:

1. Group "ear" was instructed to recall all the auditory words first, 2. Group "eye" was instructed to recall all the visual words first, 3. Group "modality" was instructed to recall all the words from one modality first, 4. Group "category" was instructed to recall all the words from one

category, first, and 5. Group "free" was instructed to recall in any order.

Subjects. The subjects were 47 volunteers from an introductory psychology class at University of California, Irvine.

Procedure. All the subjects in a group were run at the same time. They were seated two to a table in a dimly lit room facing a large white screen attached to the front wall. A Sony tape-recorder with two channels was used to trigger a Kodak Carousel slide projector as well as to present the auditory items by employing a Kodak sound synchronizer. A single list order was used for all subjects and words were drawn from the high associates of categories in the Battig and Montague (1969) norms. Auditory words were pre-recorded in a male voice and were enunciated just prior to the corresponding visual item being flashed on the screen. Thus the auditory word appeared slightly before and during the visual word; however, the method did give the appearance of simultaneity. Prior to the 20 experimental lists, there was a first demonstration list followed by three warmup lists. Written recall was in a 20 page test booklet and the MR was on a separate 160 word sheet. Subjects were told not to skip items on the MR.

Results

Table 1 presents some group summary statistics. The second row indicates the proportion of correct recall averaged over lists. Subjects were quite good at following the recall instructions, and, as expected, group "free" had the best recall rate. Next we turn to the MR data which are of principle concern to this paper.

Insert Table 1 about here

Combining all subjects there were 7,520 items presented on the MR (47 subjects $\times$ 8 items $\times$ 20 lists) and the proportion correct on MR was .658. A two-state correction for guessing model yields the probability of modality detection, D , in terms of the proportion correct, C , as $D = 2C - 1$; hence, the modality cue survived for 31.6% of the items which is well above the 0% chance level. The remainder of this section attempts to locate the source of this above chance MR performance.

Table 1 reveals that MR performance was well above chance in all groups with the least significant group being "category" ($z = 9.25$, $p < .001$). An analysis of variance showed that recognition scores did not differ among groups ($F(4, 42) = 2.24$, $p > .05$). One might expect that groups "ear," "eye," and "modality," which were instructed to organize their recall by a modality order, would do better on MR than the other two groups; however, a planned comparison reveals insignificance ($F(1, 42) = .85$). Actually the best performance on MR comes from the "free" group ($D = .432$) which was not instructed about recall order; however, since this group resulted in a greater recall rate, it is difficult to interpret its higher MR rate.

Table 1 reveals that slightly over two-thirds of the items were recalled shortly after presentation. Overall the recognition rate on previously recalled items was slightly higher than for previously unrecalled items. A sign test of the 47 subject's recognition rates on recalled and non-recalled words supports the higher recognition rates for recalled items ($z = 2.22$, $p < .05$); however, only 11 of the 47 individual 2×2 recall by recognition chi-square tests exceeded the 3.84 value for significance at $p < .05$. The overall MR performance of .617 for previously unrecalled items is highly significant (compared to .50) and represents a striking 23.4% of the items capable of modality recognition despite failure

in recall only a few seconds after presentation.

Figure 1 presents the MR performance as a function of list order averaged over groups (groups are weighted equally) for A and V items as well as combined. There is clearly no trend in Fig. 1 for early or late lists to show better MR performance. Since the time difference between original presentation and the MR varied from 1 minute to 11 minutes and the number of interpolated lists from 0 to 19 this result is quite striking.

The A items, overall, were 4.4% better on MR than V items; however, the two-choice MR task does not permit one to determine if the difference represents an auditory guessing bias as found in the Bray and Batchelder (1972) study or a differential modality detection rate. In any event the A-V difference did not vary systematically with either list order or "eye" vs. "ear" recall instructions.

Insert Figure 1 about here

Discussion

The present experiment provides further evidence that information about the input modality of an item in standard memory paradigms is retained well after the cognitive activity involving that item has ceased. Not only are input attributes such as modality prerequisite for entering an item into a memory system in order to receive a semantic analysis, but such attributes also continue to be associated with the item after it receives the semantic analysis. None of the reasonable memory props such as list recency, original recall instructions, or whether or not the item was originally recalled serve to completely explain the memory for modality. That is, close to 30% of the items presented on early lists where subjects were not instructed to recall by modality retained their modality cues even when

they were not originally recalled. Considering the extremely fast rates of simultaneous item processing, the recall occurring only five seconds after the first pair of a list, and the large number of items, this finding seems quite striking even though it is below the MR rates obtained in the free recall studies.

Subjects were able to cluster in immediate recall either by modality or by category; however, the clustering instruction did not differentially effect MR rates. This result seems consonant with the failure to find an instruction effect on MR rate in the Bray and Batchelder study. While subjects may be able to differentially use the modality cue to cluster items by modality, they seem to have little control over whether or not it is available to support modality recognition.

Even more striking is the failure in this experiment as well as in the Bray and Batchelder and Hintzman, et al. free recall studies to find any evidence for a decline in MR rate with either time or interpolated items. Not only does some of the modality information get to long term memory but it seems to get there independent of instructions to differentially attend to the cue and, once there, it seems to remain for time periods of up to 15 minutes. It is as though sensory related information represents the embodiment of a memory trace rather than merely an attribute of the trace. Unlike a computer which is constantly transforming the nature of its information, information in human memory may be represented in terms of its real world attributes. Dreams, visions, imagery, etc. may merely represent supra-threshold experiences of the sensory embodiments of our memory traces. In any event, some theoretical modifications of our notions of how information is represented in long term memory seem in order.

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Footnotes

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³Both experiments designed the MR task with three responses: 1. presented auditorially, 2. presented visually, 3. not presented. The results discussed are modality recognition given response 1 or 2. Both studies showed very high overall recognition (not response 3) rates for previously presented items.

Table 1

Recall and MR Performance Measures for Groups

<u>Measure</u>	<u>Groups</u>					Total
	"Ear"	"Eye"	"Modality"	"Category"	"Free"	
N	10	10	10	9	8	47
Recall	.707	.716	.610	.644	.771	.687
Recognition	.641	.676	.634	.625	.716	.658
Auditory	.679	.720	.648	.611	.738	.678
Visual	.604	.631	.620	.633	.695	.634
Recognition given Recalled	.640	.690	.646	.672	.733	.676
Recognition given not recalled	.644	.640	.616	.562	.662	.617

Figure Captions

Fig. 1. MR rate as a function of lists in blocks of two trials separately for A and V items as well as combined.

Figure 1

